*Rec. West. Aust. Mus.* 1982, 9 (4): 361-369

# Hollow Australites from Western Australia

W.H. Cleverly*


## Abstract

Very few complete hollow australites are known from Western Australia but imperfect ones and fragments are widespread. Cavities sometimes affected the trim in oriented flight. Partial frontal collapse of the secondary form into a cavity is shown by some specimens.


## Introduction

Australites which contain bubble cavities more than a millimetre or two in diameter ('hollow forms') and have the cavity unbreached are rare. Baker (1961; 1966a) described in detail two unusually well preserved examples from Victoria and gave shorter accounts of 14 additional specimens to total six from Victoria, nine from South Australia and one from Northern Territory (Baker 1966a; 1966b); he also described specimens with breached cavities and fragments (Baker 1963; 1966b).

The known Western Australian specimens comprise only a single example with an internal bubble cavity readily observable, a specimen in which the likely presence of a cavity can be inferred from the specific gravity, and one in which the former presence of a cavity can be inferred from the external form. There are numerous specimens with breached cavities and many fragments of hollow forms, only typical representatives of which will be described.

## Specific Gravity of Hollow Australites

The specific gravities of a localized sample of australites generally vary over a small range because of differences in chemistry or in the content of very small (sub-millimetre) cavities; the relative frequency diagram of specific gravity is usually unimodal (Chapman *et al.* 1964; Chapman 1971; Chalmers *et al.* 1976). Thus, for a sample of 486 australites from the Nullarbor Plain, Chapman *et al.* (*op. cit.* Fig. 7) found specific gravities in the range 2.39-2.47 with a clearly defined mode constituting about 45% of the sample in the 2.44-2.45 interval.

* W.A. School of Mines, Kalgoorlie, Western Australia 6430.

If an australite contains a bubble cavity more than one or two millimetres diameter but small relative to its own size, the specific gravity may still lie within the usual range for that locality. The possible presence of a cavity will not therefore be suspected and it will not be noticed except in those rare specimens where it is readily observable in transmitted light or by reflection from shallow depth. If a relatively large cavity is present, the specific gravity falls below the usual range for the locality and the cavity may be sought by using, if necessary, strong artificial illumination. Values falling distinctly below the usual range (say, 0.1 unit below) are sufficiently rare as to warrant an immediate check on their correctness or on the presence of a major cavity.

The likely volume of a cavity may be estimated if a specific gravity study is available for the district and provided also that the frequency distribution is unimodal. Let the volume of the cavity be V $cm^3$. Because the contents are either nearly vacuum or air if the cavity is breached, the specific gravity is effectively zero. The volume of the whole specimen may be obtained from the loss of weight in liquid, or for those with published data, from the mass (M)/ specific gravity (D). The specific gravity of the glass is taken as the mid-value of the modal interval. For specimen no. 1 of Table 1 from the Nullarbor Plain, mass in grams is:

$$6.388 = V(O) + (M/D - V)\ 2.445$$

from which V is *c.* 650 $mm^3$.

A bubble 'diameter' of 10.7 mm may be calculated from the volume on the assumption that the cavity is spherical. In fact, a cavity may be ovoid, double or complex with thin glass partitions, or there may be two or more distinctly separated cavities. Very rarely, the inner end of a bubble cavity may even be conical, perhaps because a rising, teardrop-shaped bubble has been frozen in position. 'Diameter' should therefore be used with an appreciation that it is only the diameter of an equivalent sphere. If the limits of the usual specific gravity range for the Nullarbor Plain (2.39-2.47) are used in calculations instead of 2.445, it may be shown that the 'diameter' of the cavity is likely to lie within the range 10.4-10.9 mm.

## Some General Principles Applicable to Hollow Australites

The aerodynamic stability of australites has been discussed by Chapman *et al.* (1962, p. 14 *et seq.*). The requirement that the centre of gravity should be in front of the aerodynamic centre means that a hollow form (conveniently visualized for present purposes as spherical with a large eccentric cavity) will orient with the larger part of the mass (thickest wall of cavity) presented forward and the larger part of the cavity (thinnest wall) to the rear. Breached cavities are thus most commonly exposed at posterior surfaces except in that minority of cases when aerodynamic and terrestrial losses have so reduced the form as to reverse the initial situation. The anterior wall is sometimes thinned to the extent that there is partial or complete collapse of the hot plastic glass in flight, occasionally to the extent that it is 'hlown through'.

Because of their higher ratio of surface area to mass, hollow forms were more rapidly decelerated in the atmosphere and heat loss by radiation was greater than for the equivalent solid forms. They were therefore less severely reduced by ablation stripping and the secondary body constitutes a larger proportion of the primary one, the shape of the posterior (primary) surface being sometimes highly domed or 'bloated' compared with that of solid forms. A good example of the highly domed form is the specimen from Hordern Vale described by Baker (1966a, Fig. 2). The Horsham specimen, for which accurate calculations were possible, lost only 25% of its volume by aerodynamic processes (Baker 1961). In conjunction with the earlier observation regarding flight orientation, a posterior surface may thus be both highly domed and hollow, sometimes a mere shell.

For stability in flight, a spherical or nearly spherical hollow form would tend to orient so that a large cavity was centred on the line of flight but it could be located eccentrically if compensating features were present elsewhere (see notes on specimen no. 1 below).

The ideal orientation of an elongated form was not attainable if it contained an eccentric cavity. Consider the stout-waisted, symmetrical dumb-bell shown in Figure 1A-C (WAM 7118 from Israelite Bay). A symmetrical dumb-bell (one with gibbosities of equal size) would orient with the long axis normal to the flight path but an asymmetrical one would orient with the larger and heavier gibbosity leaning into the airstream, i.e. inclined forward in advance of the smaller and lighter one (Chapman *et al.* 1962). The Israelite Bay specimen shows a large breached cavity on the posterior surface and located off-centre both longitudinally and laterally (Figure 1A). This cavity upset the balance and affected the flight orientation, causing the dumb-bell to trim in flight like an asymmetrical one — see Figure 1B where the orientation is demonstrated by the flow ridges being in planes approximately normal to the line of flight. The pattern of flow ridges on the anterior surface (Figure 1C) is also asymmetrical laterally, showing that the transverse axis was also tilted off the normal to the flight path. The quadrant containing the cavity was rearmost in flight and the diagonally opposite quadrant foremost. Two further examples of the trim being affected by cavities are described below (nos 5 and 8).

For an example which is complementary to the above, i.e. an asymmetrical dumb-bell which behaved like a symmetrical one because of the presence of a compensating cavity in the larger gibbosity, see Baker 1964, Pl. IVA-C, where the asymmetry is shown in Pl. IVA, the flight orientation is indicated by the relationship of the rim to the posterior profile in Pl. IVB, and the large cavity breached by the loss of the stress shell in forming a wedged core is shown in Pl. IVC. The cavity is within the remnant of the larger gibbosity and evidently compensated very closely for what would otherwise have been a more massive gibbosity inclining forward into the airstream.

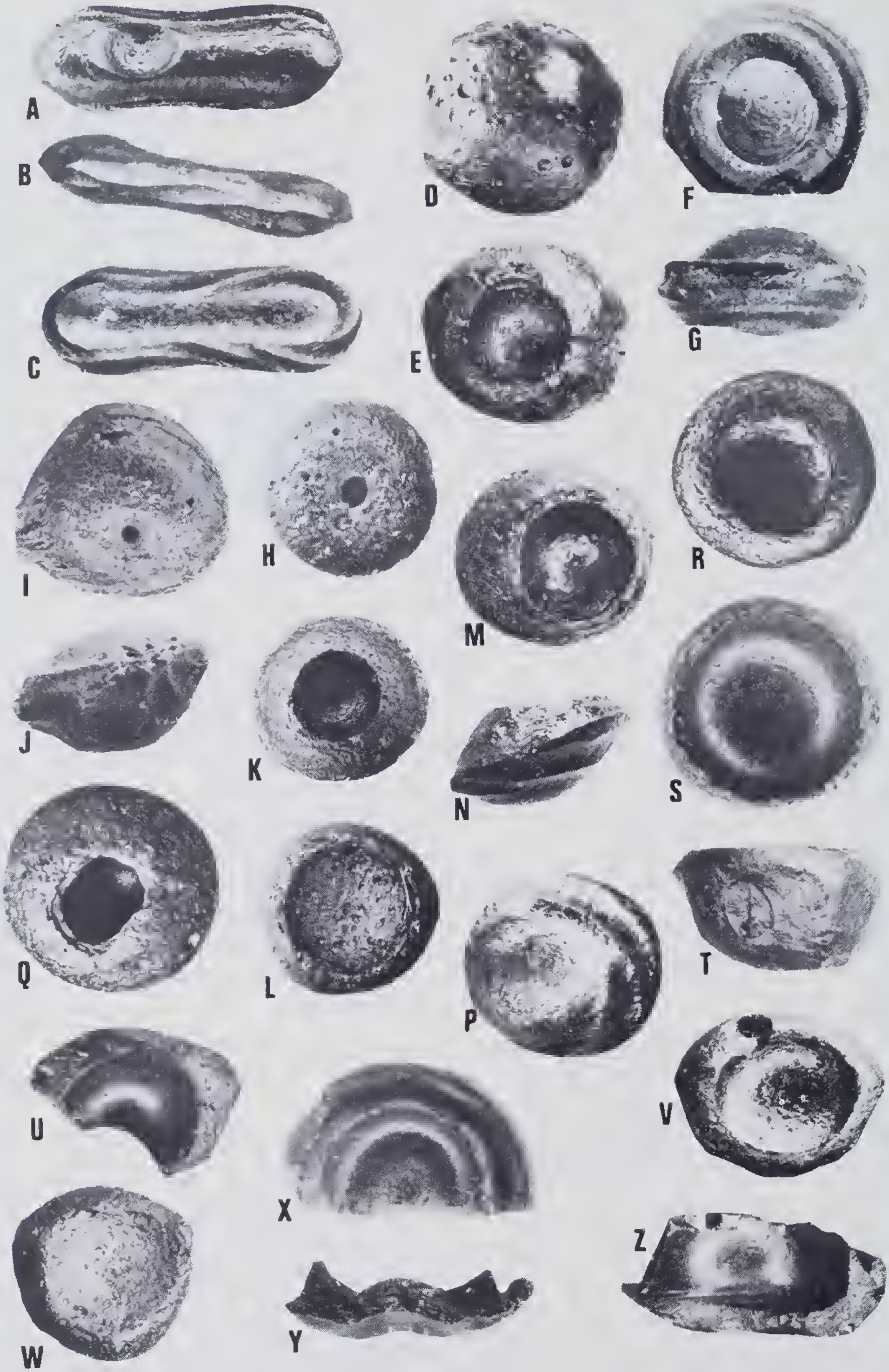


Figure 1 Hollow australites from Western Australia.

Table 1 Data on some hollow australites from Western Australia.

| No. | Collection | Site of find | Long. E | Lat. S | Form | Dimensions mm | Mass g | *D |
|---|---|---|---|---|---|---|---|---|
| 1 | SM 10 872 | *c.* 95 km NNE of Haig | 126°22′ | 30°11′ | Round core | (20.4-18.4) x 16.7 | 6.338 | 1.957 |
| 2 | L.G. Lewis | 7 km S of W of Gorge Rock | 117°55′ | 32°28′ | Round core | (60.0-57.7) x 51 x 2 | 200.53 | 2.375 |
| 3 | Tillotson family | S edge of Lake Raeside 13 km SSE of Leonora | 121°23′ | 28°59′ | Partly flanged button | (18.6-16.8) x 8.9 | 2.621 | 2.446 |
| 4 | Tillotson family | Lake Lefroy adjacent to Kambalda | 121°41′ | 31°11′ | Lens | (8.7-8.5) x 3.4 | 0.281 | |
| 5 | Tillotson family | Lake Yindarlgooda adjacent to Taurus | 121°52′ | 30°42′ | Aberrant | 13.6 x 12.5 x 7.5 | 1.275 | |
| 6 | R.E. Mitchell | Eastern Goldfields | — | — | Lens | (16.2-15.2) x 6.6 | 1.368 | |
| 7 | J.L.C. Jones | Hampton Hill Station | *c.* 121°50′ | *c.* 30°50′ | Lens | (9.0) x 3.4 | 0.213 | |
| 8 | SM 10 609 | Menangina Station | 122°02′ | 29°50′ | Lens | (12.6-11.6) x 6.6 | 0.826 | |
| 9 | SM 10 397 | Leonora district | *c.* 121°19′ | *c.* 28°53′ | Round core | (23.3-21.6) x 17.8 | 9.038 | |
| 10 | SM 11 768 | SE boundary of Mount Remarkable Station | 122°03′ | 29°26′ | Broad oval core | 22.0 x 20.4 x 11.2 | 3.504 | |
| 11 | WAM 7123 | Israelite Bay | 123°51′ | 33°37′ | Fragment of round core | (23.0-22.5) x 12.4 | 5.100 | |
| 12 | J.L.C. Jones | Hampton Hill Station | *c.* 121°54′ | *c.* 30°48′ | Fragment of hollow core | | | |
| 13 | SM 11 776 | SE boundary of Mount Remarkable Station | 122°03′ | 29°26′ | Fragment of hollow core | | | |
| 14 | J.L.C. Jones | Hampton Hill Station | *c.* 121°54′ | *c.* 30°48′ | Fragment of hollow form | | | |
| 15 | Tillotson family | Boyce Creek, Yerilla Station | 121°58′ | 29°29′ | Fragment of hollow button | | | |
| 16 | K. Jenkins | West boundary, Mount Remarkable Station | 121°48′ | 29°21′ | Fragment of hollow button | | | |

* Specific gravity

Figure 1: Hollow australites from Western Australia. For specimen numbers used below, refer Table 1. In elevational views, direction of flight is towards bottom of page.
A: Dumb-bell, WAM 7118 from Israelite Bay, view normal to posterior surface of flight, length 31.7 mm. B: Side elevation of A, oblique length 31.7 mm. C: View normal to anterior surface of A, length 31.7 mm. D: No. 1, posterior view over strong back-lighting showing location of cavity by transmitted and internally reflected light. Mean diameter of core 19.4 mm. E: No. 1, elevation (left side of D), width 19 mm. F: No. 3, anterior surface of flight, width 18 mm. G: No. 3, side elevation, width 18 mm. H: No. 4, posterior view, diameter 8.6 mm. I: No. 5, view normal to posterior surface, width 13.6 mm. J: No. 5, end elevation (left end of 1), oblique dimension 12.5 mm. K: No. 6, posterior view, mean diameter 15.7 mm. L: No. 7, posterior view, diameter 9 mm. M: No. 8, posterior surface viewed normal to plane of rim, width 12.6 mm. N: No. 8, elevation in final flight orientation, oblique dimension 12.6 mm. P: No. 8, anterior surface viewed normal to plane of rim, width 12.6 mm. Q: No. 9, posterior view, mean diameter 22.5 mm. R: No. 10, posterior view, mean diameter 21.2 mm. S: No. 11, posterior view, mean diameter 22.8 mm. T: No. 11, elevation showing well defined, ovoid 'flake scar' resulting from detachment of stress shell left of centre and remnant of stress shell at right, width 23 mm. U: No. 12, interior view, width 31.2 mm. V: No. 13, interior view, width 20.5 mm. W: No. 14, interior view, width 23 mm. X: No. 15, posterior view showing interior of cavity with central boss, width 17 mm. Y: No. 15, elevational view of lower edge of X, width 17 mm. Z: No. 16, elevational view of broken surface, width 17.6 mm.

## Descriptive Notes

The specimen numbers below are those of Table 1 which shows some basic data but omits details unnecessary for an understanding of the cavities. The australites are from the collections of the Western Australian Museum (WAM), W.A. School of Mines (SM) and the persons named in Table 1.

1 The bubble cavity is readily seen in daylight by reflected or transmitted light and is centred well off the main axis of the specimen (Figure 1D). The likely volume and 'diameter' of the cavity have been calculated above as 650 $mm^3$ and 10.7 millimetres. Compensation for the eccentric location of the cavity was provided partly by another cavity, of which a part (7.5 mm diameter) remains exposed by loss of the aerothermal stress shell (Figure 1E). Other small cavities which were perhaps within the now discarded stress shell could also have contributed to the maintenance of stability.

2 For illustrations and description, see Cleverly (1981, specimen no. 2). The specimen is an extremely large one, ranking ninth in mass amongst known australites. No specific gravity study of a representative sample of all shape types and sizes of australites is available for the district concerned. However, the specific gravities of the highly biased sample of 31 very large specimens vary so little that their mean value could be used as a basis for calculating the likely size of cavity in the exceptional one.

It will be seen in the illustrations (Cleverly *op. cit.* Fig. 2A and B) that the vesicular zones have no evident thickness, being confined to the immediate posterior surface, i.e. the remnant surface of the primary body. It is unlikely therefore that the cavity 15 mm 'diameter' could be accounted for by subsurface glass with vesicular structure.

3 Figure 1F and G. The annular depression on the anterior surface of flight could be a fold resulting from frontal collapse. A large scale profile of the anterior surface was prepared from a traverse with a travelling vernier microscope and a curve was fitted to the flanks of the surface. It is clear from the profile that the collapse of the polar region was through only about one millimetre, that being the amount of movement necessary for restoration of a complete curve. The nearest locality for which a specific gravity study is available is Mount Remarkable Station about 80 km distant to the south-east, from which a sample of 54 specimens gave values in the range 2.40-2.47 with nearly 65% of the sample in the 2.45-2.46 interval (unpublished study by W.H. Cleverly). The specific gravity of the specimen is in the upper part of the range. Even if the glass has the extreme value 2.47, the bubble could have had volume only about 8.6 $mm^3$ and 'diameter' about 2.5 mm. It seems likely that a cavity only 1-2 mm diameter was located axially because of the symmetry of the collapsed specimen and that it was effectively closed by the frontal collapse.

4 Figure 1H. The bubble cavity, which is breached by a hole 1 mm diameter, has a 'diameter' of 2.3 mm calculated from the mass of liquid required to fill it.

5 The basal remnants of what were evidently drawn-out, canoe-like extensions of secondary glass are located asymmetrically relative to the mid point of the posterior surface (Figure 1I). A small breached cavity on the posterior surface, also located asymmetrically, leads to a sub-surface cavity or cavities. The bulk specific gravity is 2.415, but after vacuum treatment to take in liquid, 2.446. Calculations suggest the volume of the cavity as 7.9 $mm^3$ and the 'diameter' as about 2.5 mm.

If the specimen is rotated on the length axis (the left-right axis of Figure 1I) until the canoe-like extensions of flange are in the mid line and the breached cavity is rearmost (Figure 1J), the specimen may be visualized in the posterior view as a canoe of complex form arising from the tendency to orient with the cavity rearward and on the line of flight.

6 Figure 1K. This specimen having a cavity exposed at the posterior surface is typical of many for which reconstruction shows the cavity to have been initially beneath the merest film of glass or even breached in the primary form.

7 Figure 1L. The breached cavity in a lens is occasionally large enough to produce a pseudo bowl form. In this example, the cavity is 7 mm diameter at the lip and the lens is 9 mm diameter.

8 A breached bubble cavity 6.5 mm diameter at the lip is exposed eccentrically upon the posterior surface (Figure 1M) and the centre of a system of ring waves upon the anterior surface is displaced eccentrically in the opposite direction to the cavity (Figure 1P). The final flight orientation must have been with the plane of the rim oblique to the line of flight (Figure 1N), the cavity rearmost, the ring waves centred upon the line of flight. Nevertheless, the shape of the specimen could have developed only with the plane of the rim normal to the line of flight and this was evidently the original orientation with some feature – possibly another cavity – compensating for the one now exposed. After the compensating feature had been removed, the flight orientation would change and a new set of ring waves would develop appropriate to it, but evidently time did not permit the re-shaping of the secondary form.

9 The volume of the breached cavity exposed on the posterior surface (Figure 1Q) was estimated from the weight of liquid required to fill it as *c.* 750 $mm^3$, equivalent to a 'diameter' of 11.3 mm. Direct measurement, necessarily approximate becasue of the breaching, suggests and axial dimension 11.6 mm and the form of the cavity would therefore have approximated to a prolate spheroid *c.* 11.6 x 11.1 x 11.1 mm. This cavity with its largest dimension parallel to the line of flight would have had the same orientation and much the same proportions as that in a very large example from Victoria (Baker 1961). These figures were estimated without the advantages of a cut specimen

and an ideal state of preservation. They do not therefore have the same degree of reliability as those given for the Victorian specimen.

10 Figure 1R. The posterior polar portion of this specimen is much reduced by weathering. The equatorial diameter of the cavity is *c.* 14 mm. An independent estimate of 14.05 mm 'diameter' was calculated from the depth of the cavity and the mass (thence volume) of liquid required to fill it, using the formula for volume of the segment of a sphere.

11 Figure 1S and T. This specimen is the anterior part of a round hollow core with portion of the stress shell still attached, i.e. it is an 'indicator' if that name may be applied for incomplete aerodynamic flaking as it is used for terrestrial flaking. The exposed remnant of the cavity is 18 mm diameter and 6.5 mm deep. The bubble 'diameter' of 22.4 mm was estimated by the same method as for the previous specimen. From it, the depth of the secondary form was calculated as nearly 29 mm plus the thickness of the posterior wall of the cavity. The shape was therefore initially highly domed.

12 Figure 1U. This fragment is typical of numerous broken hollow cores.

13 Figure 1V. This variant of the above with complex cavity is less common.

14 Figure 1W. Dished fragments of this general type are widespread. When badly weathered, the 'hot polish' of the interior of a bubble cavity is completely destroyed and it may no longer be possible to distinguish fragments of hollow forms from pieces of stress shell.

15 Figure 1X and Y. An early stage of frontal collapse has created a dimple centrally on the anterior surface and a complementary boss within the cavity, now visible because of fragmentation. For a less fragmented example (one of two) from Mount Remarkable Station, see Cleverly (1979, Fig. 5 – D1, D2).

16 Figure 1Z. This fragment shows more complete frontal collapse, the anterior wall of the cavity being almost flat and normal to the line of flight. Small, steeply-inclined remnants of the posterior shell suffice to show that the form was highly domed.

Brief accounts of two posterior shells of hollow buttons from Menangina Station have been given elsewhere (Cleverly 1973). Their anterior walls have gone completely, possibly because they were 'blown through' during ablation flight and the remnants subsequently eroded.

## Discussion

Though only a single indubitable example of a hollow australite with unbreached cavity was found, specimens with breached cavities and fragments of hollow forms are widespread. There is no reason to think that hollow australites were initially less abundant in Western Australia than elsewhere. The scarcity of well preserved specimens but relative abundance of imperfect ones reflects the fact that nearly 90% of Western Australian australites in collections are from the goldfields region of the interior where rigorous weathering and erosion processes are operative.

Hollow australites occur more abundantly in some districts than in others, e.g. on Mount Remarkable Station where 10 specimens out of 313 showed breached cavities in the range 2-14 mm diameter. This observation prompted an examination of collections of significant size from adjoining areas but the australites from neither Yerilla nor Edjudina are notable for the presence of cavities.

Partial collapse of the secondary form into cavities was shown by five of the specimens examined. I have observed a probable example of a frontally collapsed hollow core from Peake Station, South Australia and it would be surprising if other examples did not occur in eastern Australia, though they do not appear to have been reported.

## Acknowledgements

I thank Dr K.J. McNamara, Mr M.H. Lloyd, Mr and Mrs R.G. Tillotson, Mr and Mrs L.D. Tillotson, Mr K. Jenkins and Mr J.L.C. Jones for the loan of specimens and Mr M.K. Quartermaine for processing my photographs.

## References

Baker, G. (1961). A perfectly developed hollow australite. *Amer. J. Sci.* 259 (10): 791-800.

Baker, G. (1963). Australite button with internal bubble cavity containing secondary iron oxides. *Chem. d. Erde* 23 (2): 146-151.

Baker, G. (1964). Australites from Nurrabiel, western Victoria. *Mem. nat. Mus. Vict.* 26: 47-75.

Baker, G. (1966*a*). Hollow australite button with flange, Hordern Vale, Otway Peninsula, western Victoria. *Meteoritics* 3 (1): 35-53.

Baker, G. (1966*b*). Hollow australites. *Geochim. et cosmochim. acta* 30: 607-615.

Chalmers, R.O., Henderson, E.P. and Mason, B. (1976). Occurrence, distribution and age of Australian tektites. *Smithson. Contributions to the Earth Sciences* 17.

Chapman, D.R. (1971). Australasian tektite geographic pattern, crater and ray of origin and theory of tektite events. *J. Geophys. Res.* 76: 6309-6338.

Chapman, D.R., Larson, H.K. and Anderson, L.A. (1962). Aerodynamic evidence pertaining to the entry of tektites into the earth's atmosphere. N.A.S.A. Technical Report R-134.

Chapman, D.R., Larson, H.K. and Scheiber, L.C. (1964). Population polygons of specific gravity for various localities in Australasia. *Geochim. et cosmochim. acta* 28: 821-839.

Cleverly, W.H. (1973). Australites from Menangina Pastoral Station, Western Australia. *Chem. d. Erde* 32 (4): 241-258.

Cleverly, W.H. (1979). Morphology of small australites from the Eastern Goldfields, Western Australia. *J. Proc. R. Soc. West. Aust.* 61 (4): 119-130.

Cleverly, W.H. (1981). Further large australites from Western Australia. *Rec. West. Aust. Mus.* 9 (1): 101-109.

---

Received 5 June 1981 | Accepted 1 October 1981 | Published 30 June 1982